Causal Factors of Breeding Success and Frequency in Threatened Grassland Birds on the Ingula Nature Reserve, South Africa

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Abstract

The high-altitude grasslands covering the eastern escarpment of South Africa is one of the country's most valuable habitats for biodiversity, livestock and water production. The habitat hosts several threatened bird species including endangered species such as the Rudd's Lark (*Heteromirafra ruddi*) and Grey Crowned Crane (*Balearica regulorum*), and vulnerable species such as the Blue Crane (*Grus paradisea*), Wattled Crane (*Bugeranus carunculatus*), Southern Bald Ibis (*Geronticus calvus*), and Yellow-breasted Pipit (*Anthus chloris*). Avian research and monitoring have been ongoing within the recently declared Ingula Nature Reserve for more than 15 years as part of the activities of the Ingula Partnership - a partnership between BirdLife South Africa, Eskom Holdings SOC Ltd and the Middelpunt Wetland Trust - with the objective of effectively conserving birds and their habitat surrounding the Ingula Pumped Storage Scheme development. Avian monitoring on Ingula refocused in 2014 to confirm the presence of threatened species on site, followed by the determination of the breeding status of these species. An initiative was then launched to assess the breeding frequency and success of each identified species. Breeding monitoring for 13 out of the 24 occurring threatened species commenced in 2014 and was conducted for five consecutive seasons. Breeding success per season was measured in relation to the grassland management regime of that season (including both fire and grazing), as well as weather data, adjusting for dry and wet seasons. Results confirm that various grassland management regimes directly influenced the initiation of breeding activities and density of several of the species studied, while others' breeding success and frequency were more dependent on macro-weather patterns (including climate change) and fire frequency and timing. These results have direct implications for the management of highland grasslands and associated species in the given region.

Introduction

The grasslands of the Mesic Highland Grassland (MHG) region are one of the most threatened habitats due to high rates of loss, degradation and fragmentation (more than 60% of the grasslands in Southern Africa irreversibly transformed through woody encroachment or agricultural practices), with only 2.2% under formal protection (Carbutt & Martindale 2014; Colyn et al. 2020; Mucina et al. 2011). Climate, grazing and fire are important drivers of biodiversity and habitat condition within mesic grassland ecosystems, but inappropriate use of these regimes, e.g. overgrazing and too-frequent fires, can have significant impacts on species richness, abundance and diversity (Andrade et al. 2016; Little et al. 2013; Mucina et al. 2011; Maphisa et al. 2016; 2017). This reduction in abundance is most prevalent across grassland specialist species, with fire being deemed to have a greater impact than grazing (Little et al. 2013). The MHG region hosts 24 regionally threatened birds, some of which rely exclusively on grassland habitat, whilst others require both wetland and neighbouring grassland habitats to fulfil their ecological requirements (Taylor et al. 2015). Three grassland habitat specialist birds are completely restricted to this region: Rudd's Lark *Heteromirafra ruddi* (Endangered), Botha's Lark *Spizocorys fringillaris* (Endangered) and Yellow-breasted Pipit *Anthus chloris* (Vulnerable; Taylor et al. 2015; Pietersen et al. 2017). Although all three species are influenced by grassland management regimes (Little et al. 2013; Maphisa et al. 2017), climate change is also projected to have significant detrimental impacts on their distributions (Huntley & Barnard 2012). Recent studies have assessed the impact of management regimes on highland grassland species richness and associated management requirements of common bird species (Maphisa et al. 2016; 2017) in southern Africa. However, the impacts of disturbance regimes and climate, together with the subsequent management requirements of threatened bird species, require further investigation (Bento et al. 2007; Little et al. 2013). The objectives of this study are to determine the breeding activity and density of three threatened bird species selected as indicators for the MHG region of southern Africa; and to assess the interaction between management regimes (fire and grazing) and climate on their breeding activity and population density.

Methods and Study Site

The study was conducted in and around the Ingula Nature Reserve (Maphisa et al. 2016; 2017). Weather data are recorded daily on INR using a Davis Vantage Pro2 weather station. The mean annual rainfall over the study period (2014-2019) was ~840 mm. The mean maximum summer temperature was 27.6°C, mean minimum winter temperature was 7.9°C, and the hottest and coldest days recorded were 39.5°C and -1.3°C, respectively. Ecological conditions on INR, and historical management practices are described in Maphisa et al. (2016, 2017). Daily weather data were collated into monthly metrics for rainfall and temperature. All covariates were tested for association/correlation using Pearson's correlation coefficient.

Three avifaunal species out of 13 monitored, were selected as indicator species of habitat quality. The species chosen were Yellow-breasted Pipit as an indicator of grassland quality (Colyn et al. 2020), and Wattled Crane *Grus carunculata* and African Marsh Harrier *Circus ranivorus* as indicators of wetland quality (Taylor et al. 2015).

Routine systematic avian surveys have been conducted within INR since 2009 and are comprised of point and line transects, during which breeding sites were identified. Core areas noted to host pairs and/or territorial individuals were monitored monthly during the breeding seasons of each species, which resulted in year-round monthly monitoring between August 2014 and October 2019. Walked transects were used for grassland ground-nesting species (i.e. Yellow-breasted Pipit), where nest localities are highly variable between years depending on habitat structure and are not recordable from vantage point surveys. Vantage point surveys were used for wetland species (i.e. Wattled Crane and African Marsh Harrier) and allowed for the non-invasive identification of nest sites and/or assessment of breeding activity from selected vantage points using a spotting scope. Breeding surveys recorded the presence/absence of breeding, and type of observed breeding activity. For line/walked transects, the above data were recorded for each individual sighting of a focal species, thereby potentially resulting in numerous breeding pairs per survey. Monthly data for each surveyed site within each species were then converted into a binary matrix of either active breeding (1) or non-breeding (0).

Remotely sensed indices were used to test the influence of fire, grazing and vegetation cover on breeding times and densities. Remote sensing data acquisition, analyses and index creation were conducted in the Google Earth Engine platform (GEE) (Gorelick et al. 2017). All remote sensing data and related indices were created from Sentinel-2 imagery (European Space Agency 2015). Using the differenced normalised burn ratio (dNBR) we extracted two covariates: seasonal (spring vs. winter) burning extent, and time (in months) since last fire event (Key and Benson 2006; Picotte and Robertson 2011). We used the Normalised Difference Vegetation Index (NDVI) as proxy for vegetation cover (%; Maphisa et al. 2017; Colyn et al. 2020). Grazing intensity was calculated according to the large animal unit scale where possible or scored as a binary presence of livestock presence (1) or not (0; Little et al. 2013, Andrade et al. 2016; Colyn et al. 2020).

Peak monthly breeding activity for each species were visualised using the kernel density estimate function in R 3.6.3 (R Development Core Team 2017). The database of monthly periods of breeding and non-breeding were transformed into a binary matrix (0/1) for use within a logistic regression (GLMM) modelling framework using the R package lme4 (Bates et al. 2019). We collated environmental covariate data related to seasonal burn extent (ha) for winter and spring, time since last burn (n months), grazing presence/absence (0/1), grazing intensity (0-2), and climatic variables across the temporal period of assessment, with localities surveyed being treated as the fixed effect factor. The R package MuMIn was used to select the best model based on AIC. When model outputs did not clearly support a single model fit for the data, model averaging was used. Model averaging was used if models produced ΔAIC weights of less than 2 and produced comparable AIC weight.

To analyse the association between nesting density and management, a linear regression modelling framework was utilised. In cases where species datasets were not normally distributed, the package moments (Komsta 2015) and square root function was used to reduce skewness to -0.5 to 0.5. Nesting density was represented as the number of identified breeding pairs or nest sites per ha within a given management unit for grassland and wetland ground-nesting species. Breeding density was the dependant variable, which was modelled against the same grazing and fire covariates used in breeding activity analyses. However, instead of monthly covariate values, covariates represented the average of the respective breeding season for which a breeding density estimate was recorded. Out of the three species, only two (Yellow-breasted Pipit and African Marsh Harrier) had enough breeding data to include in breeding density analyses.

Results

Breeding activity

Breeding activity for all species assessed, except Wattled Crane, were associated with an increase in mean maximum temperature and number of rainfall events.

Yellow-breasted Pipit breeding was initiated in late spring and early summer and reaching the peak in December-January. The species displayed a negative association between the number of days with temperatures exceeding 32ºC and cumulative rainfall with breeding activity and conditions becoming unsuitable for breeding later during the summer. However, areas of higher grassland vegetation cover (high NDVI) yielded higher probabilities of breeding activity for Yellow-breasted Pipit.

Breeding activity for the wetland ground-nesting African Marsh Harrier *Circus ranivorus* peaked October-November. African Marsh Harriers responded negatively to cumulative rainfall, and breeding activity was strongly associated with increased NDVI (>0.4) of wetland vegetation surrounding nest sites. In addition, African Marsh Harrier breeding activity was positively associated to the number of months since a fire event, with wetlands left unburnt for more than 10 months having a significantly higher probability of breeding activity.

Wattled Crane breeding activity, however, was not seasonally restricted. Peak periods of breeding were noted in mid-winter (June-July) in 2014-2016 then shifted to early summer (November) in 2017-2019. Breeding activity was most strongly associated with the number of months since a fire event and the number of rainfall events with the probability of breeding activity increasing at recently burned wetlands and during months when it rained.

Breeding density

Only grazing intensity significantly influenced the breeding densities of Yellow-breasted Pipit. Breeding density was higher in management units with low grazing intensities and high grassland vegetation cover. Average breeding densities recorded in management units with low grazing intensities was 0.23 pairs·ha-1 (range 0.05-0.52). In units with no large ungulate grazing and high (> 1 LAU/15 ha) grazing intensities, densities were 0.08 (range 0–0.2) and 0.04 (range 0–0.14) pairs·ha-1, respectively.

Breeding densities of African Marsh Harriers ranged from 0.01–0.03 pairs·ha-1 (mean 0.02 pairs·ha-1), with an average of one breeding pair per 47.5 ha of wetland habitat. Breeding density was decreased by the presence and extent of spring burns, with results suggesting that breeding ceased if >20% of a wetland was burnt. Conversely, the extent of winter burns had no marked influence on breeding density. Wetland vegetation cover positively influenced breeding density, with NDVI values > 0.4 preferred.

Discussion [Conclusions/Implications]

The breeding activity and density of threatened grassland birds in our study were significantly influenced by climate, fire and grazing pressure. Both temperature and rainfall influenced breeding phenology, as found in other studies globally (e.g. Wesolowski and Cholewa 2009; Gibbs et al. 2011). Mean maximum temperature was highlighted as a driver of the onset of breeding in 2 of 3 study species, irrespective of varied ecological traits (see also Drake and Martin 2018). Sporadic and/or long-term changes in both rainfall and temperature can have significant impacts on many facets of breeding phenology, including the timing of breeding, and length of the breeding season, (Wesolowski and Cholewa 2009; Gibbs et al. 2011; Hovick et al. 2015; Drake and Martin 2018). Given the projected changes in both rainfall and mean temperature across the highland grassland region of South Africa (Tadross et al. 2005), shifts in the breeding phenology of highland grassland species are likely to become more prevalent.

Within our study, the influence of temperature extremes (i.e. number of days > 32ºC) on breeding activity was most marked among a ground-nesting grassland specialist species – Yellow-breasted Pipit. The increased sensitivity and susceptibility of ground-nesting species to thermal extremes is most severe while breeding (Albright et al. 2010; Carroll et al. 2015). Projected contractions of climatic niches in highland grassland species (see Huntley & Barnard 2012) were most severe for endemic highland grassland species including Yellow-breasted Pipit. Our results suggest that current climatic extremes already have a significant influence on the breeding activity of Yellow-breasted Pipit and could be applied to other ground-nesting highland grassland species with similar ecological traits. These extremes are expected to increase (Tadross et al. 2005; SAWS 2017), requiring an optimisation of nest selection (e.g. varied grass structure) as an ecological response in the context of the thermal landscape (Carroll et al. 2015). Therefore, promoting structural heterogeneity within grasslands, particularly grass height and cover, may reduce the effects of high temperature extremes during breeding, increase breeding success and promote overall abundance of ground-nesting grassland birds (Carroll et al. 2015; Hovick et al. 2015; Maphisa et al. 2017).

The cumulative impact of other key drivers of vegetation cover during breeding in our study, fire seasonality and grazing intensity, significantly reduced ground-nesting densities (ca 60-100% reduction) of our species. The detrimental impact of inappropriate disturbance regimes has been reported in highland grasslands (Jansen et al. 2001; Little et al. 2013; Andrade et al. 2016). Our study displays that the species-specific responses to, and requirements of, grassland management regimes can be highly varied, although low grazing intensities benefitted most grassland species. Similarly, the Wattled Crane was the only wetland species to respond positively to more frequent fires, whilst other species were adversely affected by frequent spring burns.

Wattle Cranes are often closely associated with large mammal grazers for food availability (Hockey et al. 2005; Bento et al. 2007). Due to the reduction and/or absence of large grazers at many wetlands in our study, fire replaces grazing by thinning out dense wetland vegetation and increasing the accessibility of tubers (Bento et al. 2007). These conflicting responses to environmental drivers show that thorough knowledge of the ecology and requirements of focal species is required to effectively direct grassland management actions. Avoiding high frequency burning and particularly spring burns and creating a mosaic of grazer intensities across management units, is likely to be the best strategy to meet the conservation requirements of habitat specialist grassland and wetland bird species.

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